LA-UR -85-1518

RECEIVED BY OSTI JUN 07 1985

CONF-850504--209

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--85-1518

DE85 012695

TITLE: ACCELERATION SIMULATION IN THE LAMPF II BOOSTER

AUTHOR(S): EUGENE P. COLTON, MP-14

SUBMITTED TO: 1985 Particle Accelerator Conference, Vancouver, B.C., Canada May 13-16, 1985

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

ACCELERATION SIMULATION IN THE LAMPF II BOOSTER

Eugene P. Colton
Los Alamos National Laboratory, Los Alamos, NM 87545

We study the evolution of the longitudinal phase space during acceleration from 0.797-7.3 GeV in the LAMPF II booster. This machine is planned to accelerate 150 μA of protons using a 60 Hz repetition rate. A multiparticle simulation program was used to model the acceleration with space charge included. The bunch population of 2.5×10^{11} protons was represented by 1000 macroparticles. During acceleration the rms longitudinal emittance grows by 3% and two particles are lost out of the separatrix.

I. Introduction

The current reference design for the LAMPF II project includes a 60 Hz booster and 3 Hz main ring. The booster accelerates 1.5×10^{13} protons from 0.797 to 7.3 GeV kinetic energy in each pulse. In this work we describe a numerical simulation of the longitudinal motion which includes space charge and inductive wall effects. The study was undertaken in order to verify that the acceleration proceeds as expected with little emittance growth and minor losses. In Sec. II we discuss the booster. In Sec. III we describe the simulation program, and then present the results in Sec. IV.

II. Booster

The booster has eight superperiods and a circumference of 350.87 m. H^- injection is used in the booster over a period of 1 ms, corresponding to 719 turns. The rf capture voltage is maintained at 0.7 MV/turn over this period. The protons are then accelerated to 7.3 GeV in 11.75 ms using a sinusoidal magnet waveform with 42.55 Hz rise frequency. The magnets are then reset for 3.92 ms. The rf program for the acceleration is described elsewhere in this conference.[1] In Fig. 1 we show the time dependence of the rf voltage V_0 and synchronous phase angle ϕ_s. Briefly, the rf voltage rises from 0.7-1.59 MV/turn during the first 3 ms in order to maintain a constant bucket area; the voltage is then held constant for the next 3 ms, and reduced linearly to 1 MV/turn over the remaining 5.75 ms. The maximum value of the synchronous phase angle $\phi_s = 42.5°$. The transition gamma of the booster is imaginary $\gamma_t = 17i$.

III. Simulation Program

The program RFSIM[2] was used to perform the acceleration. This program tracks particle trajectories in longitudinal phase space. The space-charge term is calculated from the particle density gradient in a bunch for each macroparticle (index j) at each integration step. The integration is performed twice per turn using recurrence relations obtained from the following equations

$$\frac{dW_j}{dt} = \frac{eV_0}{2\pi}(\sin\phi_j - \sin\phi_s) + \frac{e^2Nh^2g^*}{4\pi\epsilon_0\gamma^2 n_0}\frac{\partial\lambda}{\partial\phi_j} \qquad (1)$$

$$\frac{d\phi_j}{dt} = -\frac{h\eta\Omega W_j}{\beta p_s} \qquad (2)$$

where

$$g^* = g - \frac{2\beta\gamma^2}{Z_0}\left|\frac{Z_L}{n}\right| \qquad (3)$$

and the quantity

$$g = 1 + 2\ln\left[\frac{b}{a}\right] + \ln\left[\frac{p_s}{p_i}\right] \qquad (4)$$

The quantity b/a is the initial ratio of vacuum pipe size to beam size, p_s is the momentum of the synchronous particle and p_i is the starting momentum. In Eqs. (1) and (2) V_0 is the rf voltage per turn, ϕ_s is the synchronous phase angle, N is the number of particles in a bunch, ϵ_0 is the permittivity of free space, W is the variable canonically conjugate to ϕ, $W = \Delta E/\Omega$ where E is the particle energy, h is the harmonic number $h = f_{rf}/f_{rev}$, n_0 is the number of macroparticles per bunch, λ is the macroparticle line density, $\eta = 1/\gamma^2 - 1/\gamma_t^2$, Ω is the angular rotation frequency $\Omega = \beta c/R$, and R is the effective machine radius (circumference/2π). In Eq. (3) Z_0 is the impedance of free space $Z_0 = 377$ ohms and $|Z_L/n|$ represents any contribution due to inductive wall effects. For calculating the space-charge contributions the bunch is split into $\sqrt{n_0}$ superparticles.

IV. Results of Simulation

For the integration we chose $b/a = 2.0$, $p_i = 1.463$ GeV/c (T_i = 797 GeV); the inductive wall impedance $|Z_L/n|$ was arbitrarily set to 10 ohms and the harmonic number h = 70, corresponding to a starting rf frequency f_{rf} = 50.3125 MHz. We assume 60 buckets occupied so $N = 2.5 \times 10^{11}$ protons per bunch; these were represented by $n_0 = 1000$ macroparticles. These macroparticles were generated uniformly within an upright ellipse in ϕ-dp/p phase space. The starting limits were $|\phi| < 0.583\pi$ and $|dp/p| < 0.32 \times 10^{-2}$. This selection puts particles into half the available bucket area of ~ 0.13 eVs. The rms longitudinal phase-space area A_{rms} was 0.0185 eVs for a single bunch. During the simulated acceleration the beam conditions were monitored. Table I lists time, momentum, rms bunch length ϕ_{rms} and A_{rms} during the cycle. We observe that A_{rms} grows by a factor of 1.03 during the acceleration. We further show in Figs. (1) and (2) the distributions of the phase space at eight different times through the cycle; the limits of stable motion are demarcated by the confining separatrices. Two macroparticles are lost during the process.

TABLE I. Acceleration Parameters

Time (ms)	p (GeV/c)	ϕ_{rms} (deg.)	A_{rms} (eVs)
0.0	1.460	51.8	0.0185
0.5	1.493	47.4	0.0185
1.0	1.582	42.9	0.0187
1.5	1.729	38.9	0.0190
2.0	1.932	37.8	0.0190
3.0	2.487	33.2	0.0190
4.5	3.615	25.7	0.0192
6.0	4.935	[illegible]	0.0191
9.0	7.316	15.8	0.0191
11.7	8.184	14.9	0.0190

References

1. E. P. Colton, "The rf program for LAMPF II," these proceedings.

2. Y. Cho et al., IEEE Trans. Nuc. Sci. NS-28, 3040 (1981).

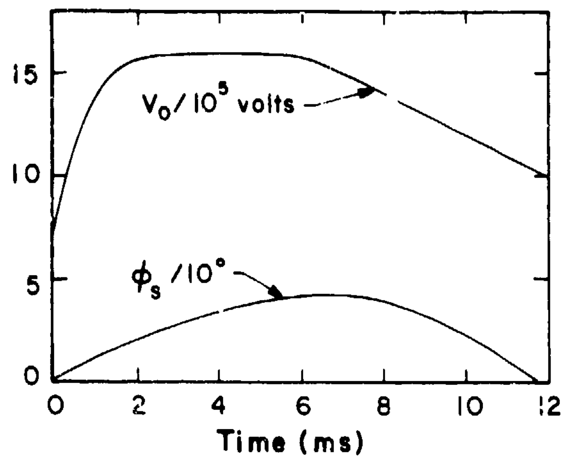

Fig. 1. RF program for LAMPF II booster.

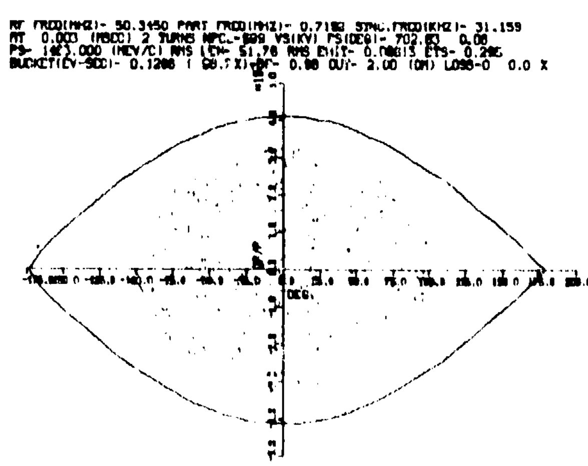

Fig. 2. Injection bucket and 1000 macroparticles.

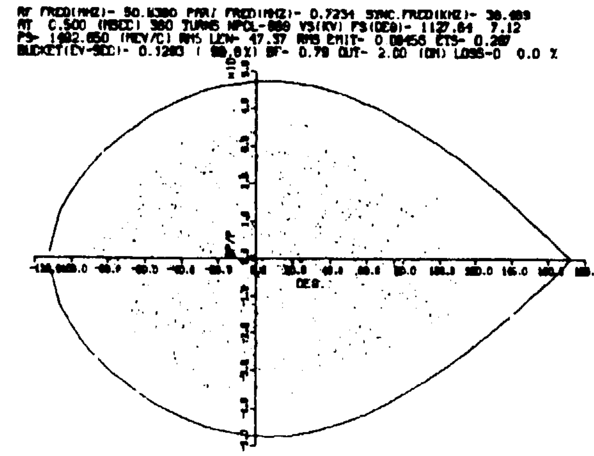

Fig. 3. Conditions at t = 0.5 ms into acceleration.

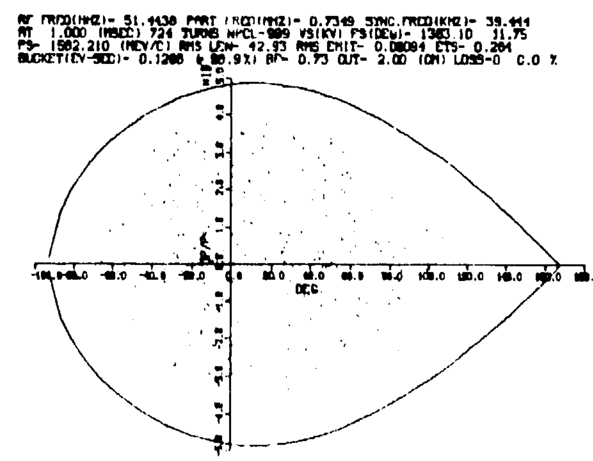

Fig. 4. Conditions at t = 1.0 ms.

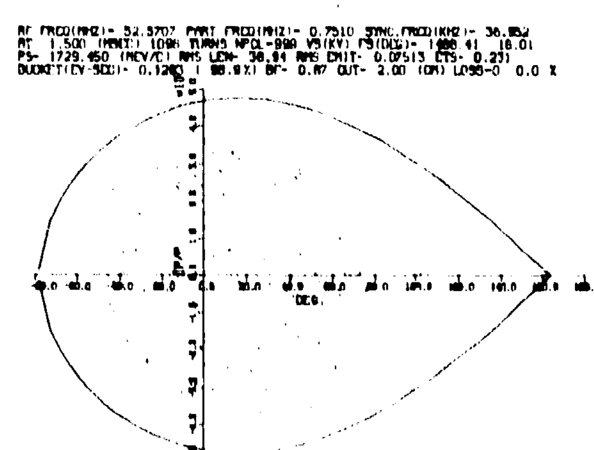

Fig. 5. Conditions at t = 1.5 ms.

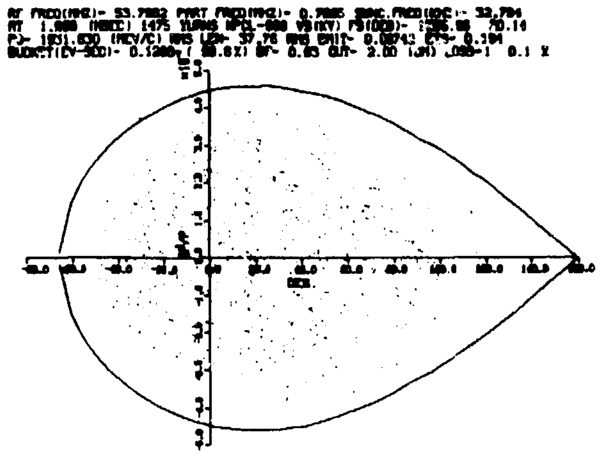

Fig. 6. Conditions at t = .0 ms.

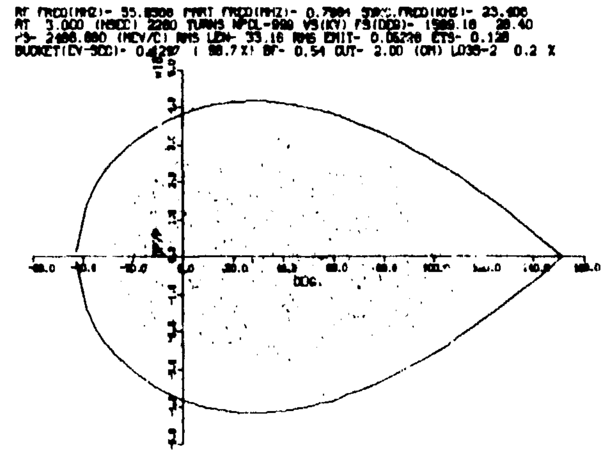

Fig. 7. Conditions at t = 3.0 ms.

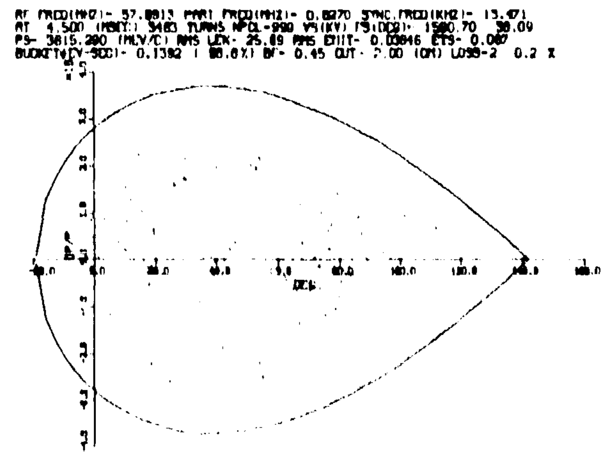

Fig. 8. Conditions at t = 4.5 ms.

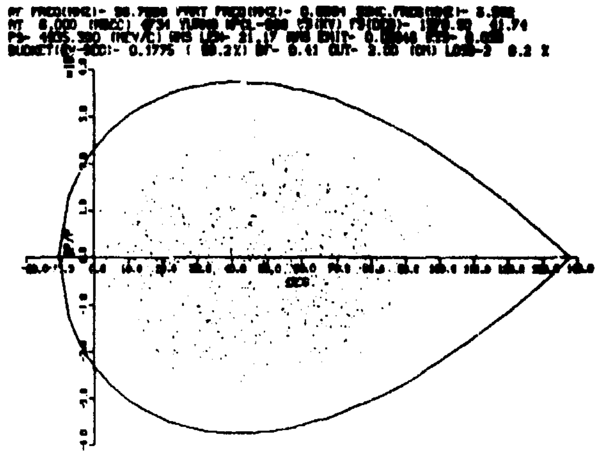

Fig. 9. Conditions at t = 6.0 ms.

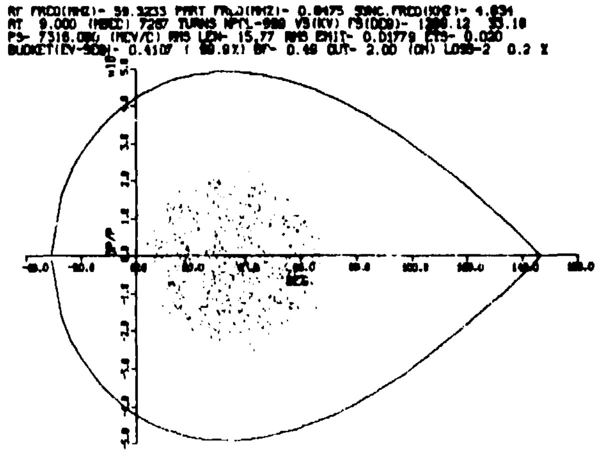

Fig. 10. Conditions at t = 9.0 ms.

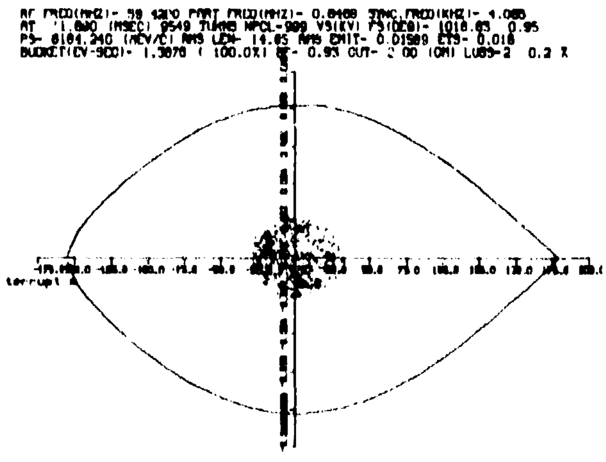

Fig. 11. Conditions at t = 11.7 ms.